# A MERCURIAL BAROGRAPH OF HIGH PRECISION.

By Professor CHARLES F. MARVIN. Dated Washington, D. C., September 4, 1908.

The pressure of the air and its variations constitute some of the most important factors in meteorology and the dynamics of the earth's atmosphere, and many excellent instruments have been devised and employed for many years to measure and continuously record these data.

The literature of the subject is already very full and should be consulted by readers seeking complete information relating to such instruments. The object of the present paper is to describe in detail a new form of siphon barograph designed by the writer some years ago, and which has since operated with such highly successful and accurate results as to prove the instrument distinctly superior to any of the numerous forms[1] that have been extensively tested at the Central Office of the Weather Bureau in Washington, D. C.

## COMPENSATED SIPHON BAROGRAPH, MARVIN SYSTEM.

This instrument is illustrated in figs. 1 and 3 and belongs to that class in which the record is made mechanically without the interposition of any clock-work or electric mechanisms to overcome friction, etc. To secure satisfactory records on a highly magnified scale by this method, it is indispensable that the friction involved in writing the magnified record be removed to the last degree. Experience has demonstrated that this has been accomplished in the arrangement described, and this instrument proves to be exceedingly accurate and far more reliable than any of the types in which indirect registration is employed. This results from the fact that in the latter class of apparatus the clock and electrical mechanisms which effect the registration act in a certain sense indirectly and themselves introduce certain variable errors. Moreover, the weakening of batteries or the failure of electric mechanisms from time to time, result in interruptions in the record that do not occur in the system of direct mechanical registration employed in the new instrument.

### *Compensated siphon.*

The barometer of this instrument is a special form of siphon quite clearly shown in fig. 1, and with dimensions marked in fig. 2. The long and short branches consist of simple, straight tubes. These are narrowed down at the lower ends where they are fitted into the upturned branches of the bend, or U. The tubes, in fact, form hollow stoppers carefully fitted and ground in. The tops of the U above the ground joints are provided with bells, or cups, of ample size, which have a lip formation on one side. This three-piece construction enables the barometer to be filled in the most satisfactory manner, but more especially the siphon, after being once filled, can be assembled or dismantled and transported without loss of the vacuum. The mercury in the open leg of the siphon in the course of time becomes more or less fouled with oxidation, the accumulation of dust, etc. The construction described permits of removing the short branch of the siphon at any time with very little trouble. The tube and excess of mercury can then be thoroly cleaned and replaced. The following details concerning the mounting of the siphon will explain this part of the instrument.

*Filling and installing the siphon.*—The ordinary siphon tube made in one piece of any considerable size, is very difficult to fill and secure a good vacuum, and it can not then be easily cleaned or transported. The present three-piece construction overcomes these difficulties very perfectly and requires only that the long straight branch be carefully filled. This may be done by almost any of the methods described hereafter, but the air-pump method (see fig. 7) is undoubtedly the best.

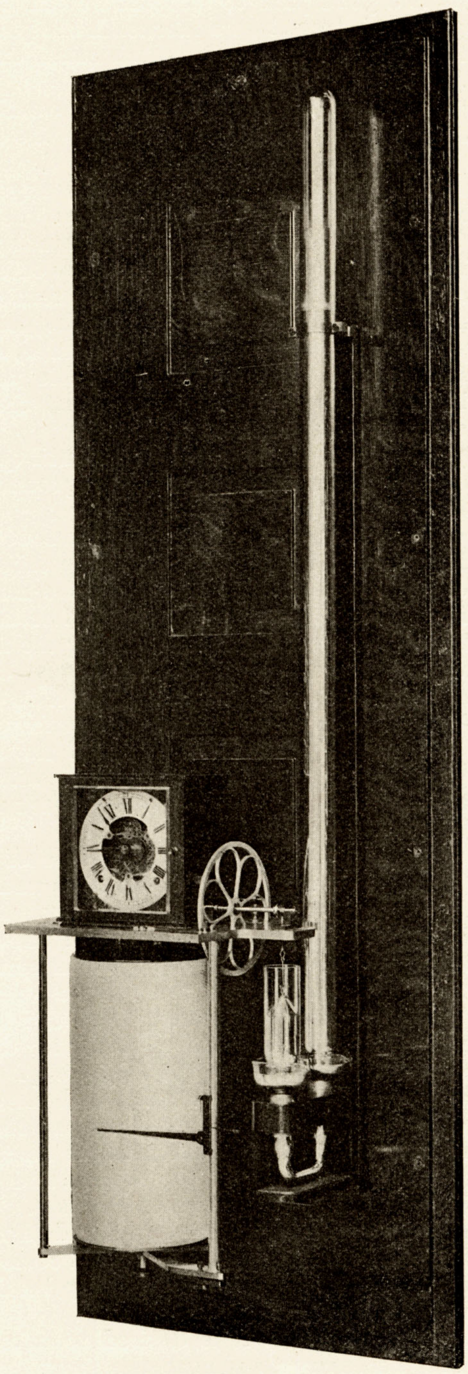

FIG. 1.—General view of compensated siphon barograph, Marvin system. Cover removed.

When the siphon is to be installed it will be well to prepare the ground joints by the application of a little lubricant, such as vaseline, tallow, or, if available, special stop-cock lubricant, very sparingly rubbed over the external surfaces of the tubes. A little pure mercury is next filtered into the bend or U-shaped section. Little air bubbles, if any appear, should be excluded by tilting the tube and causing the mercury to flow about in a manner that will accomplish this result. When the mercury covers the ground surfaces the short branch of the siphon should be carefully inserted and the whole secured to the instrument in the manner provided. More pure mercury is now added to the open cup until it is filled nearly to the brim. As some mercury is likely to be spilled in some of the subsequent

[1] A description of several of these instruments will be found in the Annual Report of the Chief Signal Officer, 1887, Part 2, and in U. S. Weather Bureau Circular F, Instrument Division, 3d ed., 1908.

operations, it is a good plan to support a clean porcelain or glass photographer's tray close underneath the plate supporting the bend. This will serve to catch small excesses that may escape.

The long branch of the siphon, filled to overflowing with clean mercury, may now be lifted and, while the open end is temporarily closed firmly with the finger tip, the tube is carefully inclined in a manner that will permit the finger and point to be dipt below the free surface of mercury in the cup. Still supporting the weight of the heavy tube so that the end does not bear with undue pressure upon the parts of the cup, the whole is carefully and slowly brought into a vertical position. When the elevation of the tube has reached the point at which the mercury begins to leave the top of the tube, an assistant should be in readiness to catch in a suitable vessel (a dry, clean, drinking glass will answer very well) the excess of mercury that overflows from the open cup.

The heavy tube must be fully supported until quite vertical and the end only then inserted into the ground joint and rotated a little as it is faced to the front.

Certain precautions must be observed thruout the operations just described. (1) The tip end of the tube must not, under any circumstances, be lifted out of the mercury after the finger is removed, and especially not after the mercury has begun to flow out of the tube. (2) After the flow of mercury has started the elevation of the tube must be slow and gradual, otherwise the column of mercury tends to oscillate or surge up and down, and may threaten to uncover the point of the tube in the cup. (3) Any lowering of the tube causes the mercury to recede into the vacuum, and will empty the cup unless the supply is kept up by pouring back some of the excess that has already overflowed.

Having finally seated the long branch, some of the excess of mercury must be restored to the siphon and the level brought up to the proper point in the open leg. At the completion of these operations one of the cups of the bend is full to overflowing with mercury, and the other is nearly or quite empty. Some of the mercury in the full cup can easily be removed by splashing it out into a cup held to receive it and using a piece of card or an ivory paper-folder for the purpose. A little mercury may be added to the empty cup.

*To clean the mercury.*—When the glass and mercury in the open leg become soiled with prolonged use, all that is necessary to clean these parts is, first to remove the float, then carefully loosen the short branch of the siphon and permit the excess of mercury to overflow into a clean glass. When thus emptied the open branch may be removed and thoroly washt, cleaned, and replaced. Most of the dirt will come away with the glass tube, but the mercury may easily be filtered and replaced perfectly clean and bright.

*To dismantle the siphon.*—If it is desired to take down the siphon it is first necessary to remove the short branch, carefully collecting the excess of mercury, and then, after separating the ground joint of the long arm, the latter is slowly inclined while an assistant steadily pours mercury into the open cups to supply what recedes into the vacuum. When the tube is entirely filled the finger may be slipt over the open end while submerged in the mercury and the whole tube removed.

*Temperature compensation of the siphon.*

By giving the siphon barometer proper dimensions the influence of temperature can be eliminated for all practical purposes. The compensation operates so that temperature changes which affect the whole instrument uniformly, produce no sensible change in the level of the mercury in the short or open branch of the siphon. The actual difference of level of mercury in the two branches will, of course, be affected by temperatures in the usual way, but not the absolute position of the surface in the open leg. Since all measurements are made only on this surface in many forms of mercurial barograph, it is very desirable to realize in the design of such instruments this condition of automatic compensation for temperature.

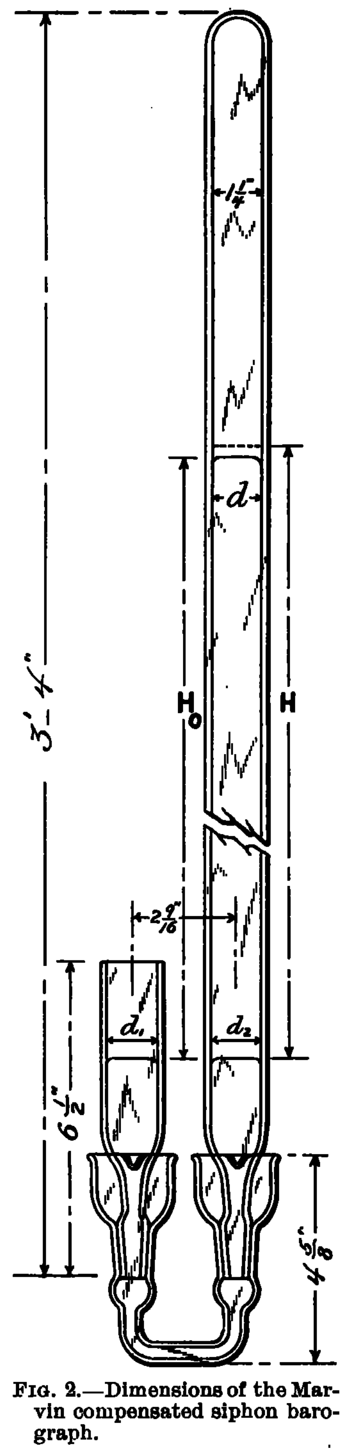


FIG. 2.—Dimensions of the Marvin compensated siphon barograph.

The physical principle utilized for this purpose is found in the different rates of expansion of mercury and glass or whatever material is used for the tube or envelop for the mercury. If the coefficient of expansion of the envelop were zero the mercury would rise slightly in the open leg with rise of temperature, and vice versa. As the theory of this temperature compensation is not stated in the ordinary text-books of physics and meteorology, and in fact does not appear to be widely known, it seems worth while to present it here briefly. The theory was developed by Prof. G. W. Hough[2] in 1862, and later by Goulier.[3]

Let $m$ = cubical expansion of mercury per unit temperature.
$g$ = cubical expansion of glass per unit temperature.
$V_0$ = volume of mercury in instrument at temperature $t_0$.
$d$ = diameter of tube at top of column in vacuum.
$H_0$ = height of column at temperature $t_0$.
$H$ = height of column at temperature $t$.
$d_1$ and $d_2$ = diameter of the two branches of the siphon at the level of the top of the column in the open branch.

We assume that the pressure remains constant, therefore the barometric column for a change of temperature must change its length by an amount represented by the expression $m(t-t_0)H_0$, otherwise its hydrostatic pressure will be altered; that is,

$$H - H_0 = m(t - t_0) H_0.$$

Neglecting small quantities of a second order of magnitude, the volumetric increase in the barometric column will be the expression

$$\tfrac{1}{4}\pi d^2 m (t - t_0) H_0,$$

which is the change necessary to preserve hydrostatic equilibrium.

Now, the actual apparent change in the volume of mercury in the tube will depend upon the differential expansion of mercury and glass, and is given by the expression:

$$V_0 (m - g)(t - t_0).$$

When this increase is just equal to that necessary to preserve hydrostatic equilibrium, all the expansion will seem to take place in the vacuum chamber, and no change will occur in the level of the mercury in the open leg. To realize this condition, we have:

$$V_0 (m - g)(t - t_0) = \tfrac{1}{4}\pi d^2 m (t - t_0) H_0,$$

whence

$$V_0 = \frac{\pi d^2 H_0}{4} \frac{m}{m - g}.$$

The expression

$$\frac{\pi d^2 H_0}{4}$$

is the volume of the barometric column supposing the diameter is the same thruout as at the top.

The cubical coefficient of expansion of mercury, $m$, is a very definite quantity and, for barometric work, may be taken to be .0001010 per degree Fahrenheit. The expansion of glass is much smaller and varies considerably, ranging, according to Regnault's measurements, from .0000145 for common white tubing to .0000118 for the hard French and crystal tubes. That is to say, the whole volume of mercury in a siphon for compensation must be about

$$V_0 = 1.168 \frac{\pi d^2 H_0}{4}$$

if the siphon is made of common tube glass, or

$$V_0 = 1.132 \frac{\pi d^2 H_0}{4}$$

if it is made of French crystal glass.

No great exactness is necessary in determining the volume $V_0$. It will suffice to assume $H_0$ equal to the mean barometric pressure at the place of observation, and the total volume of mercury should be about 17 per cent more than requisite to fill a column of height $H_0$ and diameter $d$.

If the bend of the siphon is of wide bore, the open leg and bend must be very short, e. g., $30 \times 0.17 = 5.1$ inches, otherwise $V_0$ will be too large. For this reason, as well as for convenience of construction, the bend is best made of smaller diameter than the main tube, as shown in the illustration.

If the long arm of the siphon is of full width only in its upper portion, and the remainder of the tube is of slender cross section, then the whole volume of mercury will be deficient unless the bend is long or of wide bore which are not desirable features of construction.

The theory given above takes account only of the influence of temperature on the mercury and glass tube. The effects that result from changes in the mechanisms for transmitting and inscribing the record, as described later, and for holding the glass barometer tube itself, all require consideration; but fortunately these are in the main so small, especially when considered in relation to the highly magnified scale on which the record is inscribed, that they may be neglected. In any case they can be incorporated with the mercury effect so that by adding or removing small amounts a certain total volume, $V_0$, of mercury at temperature $t_0$ may be employed, such that all effects of temperature on the whole apparatus will be automatically compensated.

If the siphon is not compensated, then the volume of mercury at temperature $t_0$ is $V_1$, which in general will be greater than $V_0$, but may be less; and a small correction will be required, the amount of which will be simply the apparent expansion of the excess of mercury occupying the bend and short leg of the siphon. This expansion may be imagined to simply lift the whole column of mercury a small amount, $\Delta h$.

The volumetric expansion will be

$$(V_1 - V_0)(m - g)(t - t_0)$$

and the rise of mercury, $\Delta h$, is given by the expression

$$\frac{\pi}{4}(d_1^2 + d_2^2)\,\Delta h = (V_1 - V_0)(m - g)(t - t_0).$$

In general, $d_1$ and $d_2$ will be made sensibly equal, and in fact equal to $d$, hence:

$$\Delta h = 2(V_1 - V_0)\frac{(m-g)(t-t_0)}{\pi d^2}.$$

Let $y$ be the amount by which the mercury in the open leg of the siphon stands higher, for example, than required for compensation. Then, since an equal excess of mercury occupies the opposite branch of the U, we have:

$$V_1 - V_0 = 2\frac{\pi d^2}{4} y.$$

Hence,

$$\Delta h = y(m - g)(t - t_0),$$

or, for ordinary glass,

$$\Delta h = 0.0000865\, y\, (t - t_0).$$

*Magnifying and recording mechanisms.*

In the barograph illustrated, the barometric changes are magnified five times and recorded on a vertical drum adapted to embrace a change of 2 inches of pressure and revolving once in three days, moving at the rate of about a quarter of an inch per hour. A long experience with a variety of scales indicates that records on time and pressure scales of about the above proportions give, on the whole, the most satisfactory and graphic picture of ordinary barometric oscillations. Even the sudden changes that sometimes accompany thunderstorms are very well brought out; but for the most detailed effects of this character a more rapid time scale is necessary. The magnification is sufficiently great to show admirably the small fluctuations of a few thousandths to some hundredths of an inch that sometimes occur for hours at a time.

In the siphon form of barometer the change of level of the mercury in either leg is only half of the whole change, assuming both legs to have the same diameter, and, since we measure effects in the open leg only and desire a fivefold magnification, it follows that an actual tenfold magnification of the

[2] Hough, Prof. G. W., Annals of the Dudley Observatory, Albany, N. Y., 1866, Vol. 1, p. 88.
[3] Goulier, C. M., Comptes rendus, 1877, Vol. 84, p. 1315.

movements of the float are necessary. This is accomplished by a large and small wheel operating on the principle of the wheel and axle, as may be clearly seen in figs. 1 and 3. This construction provides a perfectly balanced system which is itself neutral in all positions and at the same time admits of a wide range of movement, results impossible to secure with lever systems commonly employed in case of this kind.

In order to secure strength of construction and at the same time reduce friction to a minimum the multiplying wheels and axle are mounted on carefully designed and constructed ball-bearings, each cell containing only six balls, each one-sixteenth inch in diameter. The ends of the axle entering the ball cups are cones of 70°.

A conical steel float, with the base somewhat hollowed out so as to conform fairly well to the shape of the surface of mercury, rests lightly upon the top of the column and is suspended from the small drum of the wheel and axle system by means of a narrow platinum ribbon about 0.001 inch thick. The pen-carrier is suspended by a very fine copper wire running in a groove in the rim of the large wheel, the diameter of which is approximately 5 inches, while that of the drum is one-tenth as great. The exact ratio of these wheels is planned to realize a fivefold magnification of pressure changes; due account being taken of any slight differences in the diameters of the open and closed chambers of the barometric column.

To realize a condition of minimum friction great attention is necessary in the design and arrangement of the pen-carrier; first, its weight is the least practicable since the mass of the float must be somewhat in excess of ten times that of the pen-carrier, and any unnecessary weight in these parts introduces avoidable friction on the axle. Second, the pen-carrier is guided and constrained to move, without sensible looseness, in a definite vertical line by sliding along a fine, stretched wire; but the whole arrangement is so poised and balanced that if not disturbed by exterior influences the carrier will rise and fall in exactly the same vertical line, as nearly as may be, even when the wire is removed. This adjustment serves to eliminate any sliding friction experienced by the pen-carrier, not absolutely essential to constraining the pen to the desired vertical line. Finally, the contact pressure of the pen on the record sheet is no greater than essential and results from a small residual gravitational tendency of the carrier to rotate the pen point against the record sheet with a very gentle pressure. The siphon tubes are about $1\frac{1}{4}$ inches in diameter and the float is only slightly smaller. This gives a moving force capable of overcoming the unavoidable friction in a highly satisfactory manner, and the absence of any complicated mechanisms renders false and interrupted records almost an impossibility.

*Time checks on record sheet.*

As thus far discribed the barograph is complete and with the aid of the driving clock and drum, which require no further description, gives exceedingly accurate and continuous records. The detailed analysis of barometric records generally requires hourly readings. When record sheets with ruled scales for pressure and time are employed, there is always a difficulty in setting the record so that the ruled hour lines on the sheet indicate the true time. A similar difficulty arises in setting the pen to the correct point on the pressure scale. This, however, is of slight consequence if sheets are properly printed, cut with uniform margins and carefully placed on a cylinder.

To easily secure an equally satisfactory result with the time record the driving clock is provided with a dial and hands in the usual fashion. These moving continuously day after day enable the clock to be regulated to keep correct time, a result very hard to secure when the rating is done on record sheets that are frequently changed. More especially, however, the barograph is equipped with a special time-marking device which automatically operates once each hour at the instant the minute hand of the clock reaches XII, or the zero point of the hour. Nearly all the time lines are omitted from the printed rulings of the record sheet, and the marker operates so as to lift the float a few hundredths of an inch and immediately release it suddenly. This causes the recording pen to oscillate a few times up and down, and to inscribe a short transverse line across the pressure record. These transverse strokes are, in fact, the hour lines for the entire record, and are inscribed with all the accuracy required.

A further advantage results from the action of the time marker. Since the float is slightly raised from the mercury, and subsequently executes several oscillations, there results a general breaking up and renewal of the forces of buoyancy and capillarity which determine the exact position of the float, and at the end of the oscillations any failure of the pen to return exactly to its original position is an index of the magnitude of errors that arise partly from friction and partly from the variations in the capillar and buoyant forces which support the float.

Discontinuities of several thousandths of an inch, due to these causes, are sometimes found and thus render apparent small errors of this kind the existence of which would otherwise be only conjectured.

*The time-marker.*—The time-marker is shown in fig. 3 and consists of an electromagnet, the circuit of which is closed by a spring contact momentarily operated by the minute hand of the clock as it passes the XII point of the dial.

The armature of the magnet is shaped thus: ⏋, as seen in the picture. A long, light, horizontal rod is pivoted at the depress end of the ⏋-formed armature, and is partly lifted by the pull of a spring also carried on the armature. The outer end of the long arm is tipt with a bit of soft rubber, and is loaded with a small counterweight which rests lightly on a small post or stop provided for that purpose.

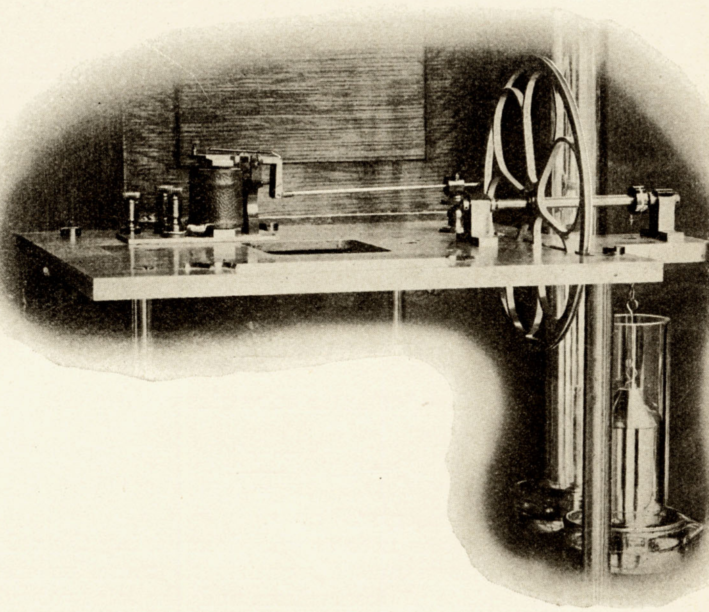

FIG. 3.—The time-marker of the Marvin siphon barograph.

The action of the marker is as follows: When the armature is suddenly pulled down upon the magnet the rubber-tipped rod is thrust forward against the rim of the large wheel. The inertia of the counterweight suffices to overcome for an instant, but only for an instant, the pull of the spring previously mentioned. In this instant, however, the rubber-tipped end of the rod has engaged the rim of the wheel, and the slower-acting pull of the spring then lifts the rod and thus turns the wheel a small distance (one to two-tenths of an inch). As soon as the armature is released by the breaking of the contact in the clock the wheel and float are released and oscillate freely for a moment, producing the results already fully explained.

The recording drum makes a complete rotation in seventy-four hours, i. e., three days and two hours. Sheets ordinarily are changed at any time between 11 a. m. and noon—preferably shortly after 11 a. m. The new record is therefore fully started before noon, and a check reading of the standard barometer is made as nearly as possible at noon. This furnishes a check observation for determining the starting error of the barograph. Further checks may be obtained subsequently from the regular observations at 8 a. m. and 8 p. m.

A small section of an actual record is reproduced in fig. 4, which shows some of the more marked and periodic oscillations that sometimes occur. The fine details accurately brought out in these records are of themselves an index of the exact manner in which the pen responds to minute changes of level of the mercury.

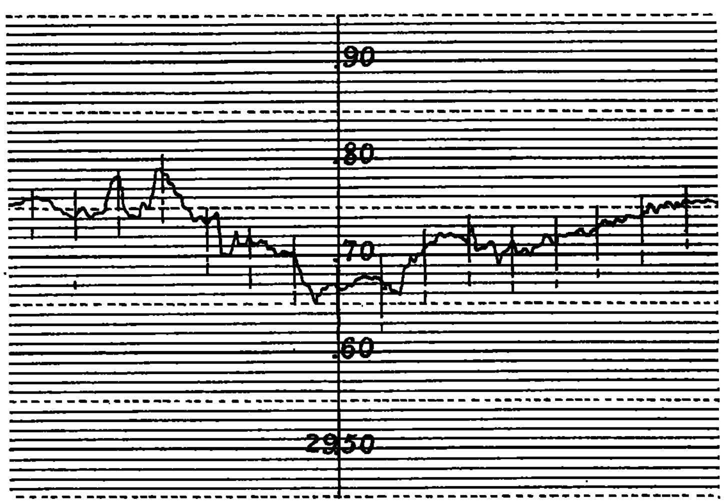


FIG. 4.—Small section of an actual record by the Marvin siphon barograph.

HOW BAROMETER TUBES MAY BE FILLED.

Processes that may be followed in filling barometer tubes for high-grade instruments are so rarely described and so little known, that a short description of some methods frequently employed at the Weather Bureau with highly satisfactory results will doubtless be of interest to a number of readers and serve to accomplish the purposes of this paper more fully.

The object of any filling process is simply to introduce pure mercury and totally exclude all air, moisture, or other foreign matter, especially of a gaseous nature, that may possibly later enter the barometric vacuum and cause errors by the pressure it exerts on the top of the mercurial column.

*Cleaning the tube.*

In all cases it is of great importance that the inside walls of barometer tubes be perfectly clean. New tubes are thoroly cleaned with whiting or other suitable means while open at both ends, and while still warm and dry the top end is closed and the cistern end tapered and finally fused shut.

Small tubes (one-quarter inch and less) that have become soiled by use, exposure, etc., can not be easily cleaned properly and such are never used a second time in the Weather Bureau work. The methods given in a paragraph below for cleaning larger tubes may, however, be used even with these. The results obtained by the funnel method will be much better if the walls of the tube are strongly heated just before filling and warm mercury introduced while the tube is still warm.

*Cleaning large tubes.*—Tubes that have contained mercury of which oxidized and impure portions may still adhere more or less closely to the wall, should first be treated with dilute nitric acid (one part in twenty), and then thoroly rinsed with plenty of water. Ammonia or some other alkali may be added if desired, after which the operations described below should be followed.

Introduce several inches of soapy water and whiting with tissue paper pulp. It is often easiest to twist up loosely and put into the tube several small sheets of cheap straw or manilla tissue paper, and add the water and whiting afterwards.

This creamy mass can be strongly shaken about inside the tube, and serves to scour the walls in a very satisfactory manner. It is then removed by copious rinsing with clean water, ending finally with some changes of distilled water. After draining some minutes several applications of strong alcohol in moderate quantities are introduced and drained out and the tube given a final draining for a half hour or so, if convenient, after which it is ready for drying and filling.

*Funnel method.*

It may seem that the desired result could be obtained by carefully introducing clean mercury thru a long, slender-stemmed funnel reaching quite to the bottom of the barometer (see fig. 5). A suitable funnel may easily be made by drawing down the end of a short piece of rather wide tubing. Such a method is sometimes used and will, indeed, give approximate results, but it will be found upon investigation that while the mercury seems to drive out all the air, yet a good deal will still be found in the vacuum. Originally, this air mixt with water vapor is strongly adherent to the walls of the glass tube by reason of a peculiar property of this character which glass is found to have. When the barometric vacuum is formed, some of the gaseous matter thus attached to the tube is liberated and, by its pressure, depresses the mercurial column several hundredths of an inch, as has been shown by careful experiments.

One very simple and excellent method of driving off nearly all the air and moisture condensed on the glass walls is given in the next paragraph.

*The boiling method.*

This is a simple method commonly employed with all small tubes, say one-fourth inch diameter, more or less; such, for example, as are required in the several types of barometers that are employed for the ordinary station observations. Much larger tubes are frequently boiled, but these when more or less full of hot mercury are heavy to handle, a strong heat is required, and the danger of serious accidents is considerable.

It is well, at first, to warm more or less the whole tube and the cup of clean filtered mercury from which the supply is drawn should also be gently warmed.

Sufficient mercury to fill the tube three or four inches is introduced by the aid of a funnel such as shown in fig. 5, except that the slender stem need be only two or three inches long. In the absence of such a funnel it is quite as well to employ a small paper cone of the kind commonly used in filtering mercury. The mercury in the tube is then boiled carefully over a good Bunsen burner flame (see fig. 6). For this purpose the tube is held easily in the hands and moved continuously thru the flame and rotated so as to avoid undue local heating of the tube. As the heating proceeds, the air and moisture vapor first form minute silvery-white bubbles, giving the tube a frosted appearance. These enlarge, and after actually boiling the mercury for a while all evidence of formation of bubbles on the wall disappears and further boiling of the mercury takes place with sudden bursts and a sort of violence, accompanied by sharp metallic clicks as the portions of the boiling mercury strike each other or the walls of the tube. When it is apparent the gases on the walls of the tube have been driven off sufficiently, a fresh quantity, three or four inches, of warm mercury is added, and this portion then heated and boiled. The line of separation between the new and the old mercury is rendered plainly conspicuous by the frosted appearance previously mentioned.

These operations are repeated until the mercury reaches 3 or 4 inches from the tip of the tube, the latter portion being filled by the careful use of the funnel without boiling.

FIG. 5.—The funnel method of filling barometer tubes.

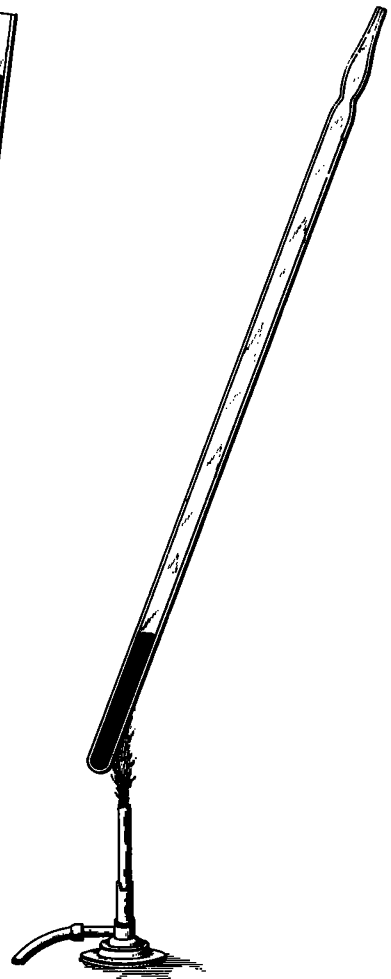

FIG. 6.—The boiling method of filling barometer tubes.

If the walls of the tube are clean and dry this method is easy to employ and gives very high vacua. The presence of dirty spots on the glass and tubes with damp walls cause greater or less trouble and possibly protracted boiling with other complicated effects.

*The air pump method.*

This method, with numerous modifications, has been employed by the writer in a large number of cases with very satisfactory results. The method requires a good air pump, drying tubes, beakers, burners, stands, etc., such as are generally available in any physical laboratory.

The apparatus is arranged as shown in fig. 7. The exhaustion and funnel tube F*f* will probably require to be made up to suit requirements by some one a little familiar with simple glass-blowing operations. For most purposes this may be attached to the barometer tube by a short piece of soft, pure rubber tubing R. The outside end of the funnel is drawn down into a long capillary extension which is bent several times as shown so as to dip into the cup of mercury, M. Too fine a capillary should be avoided, and it is generally necessary and easy to weaken the capillary, as at *a*, by heating it a little so that later the tube will break off at this point when a torsional strain is put upon it by twisting the bent extremity, *a*, *b*, *c*. The point at *c* is closed by fusion to begin with. A stop-cock may be employed, as at *d*, and in this case the breaking of the tube is not required, but if the stop-cock leaks even a little the result may be defective and the arrangement first described is often best.

*Drying and filling the tube.*—In order to dry the tube it is alter-

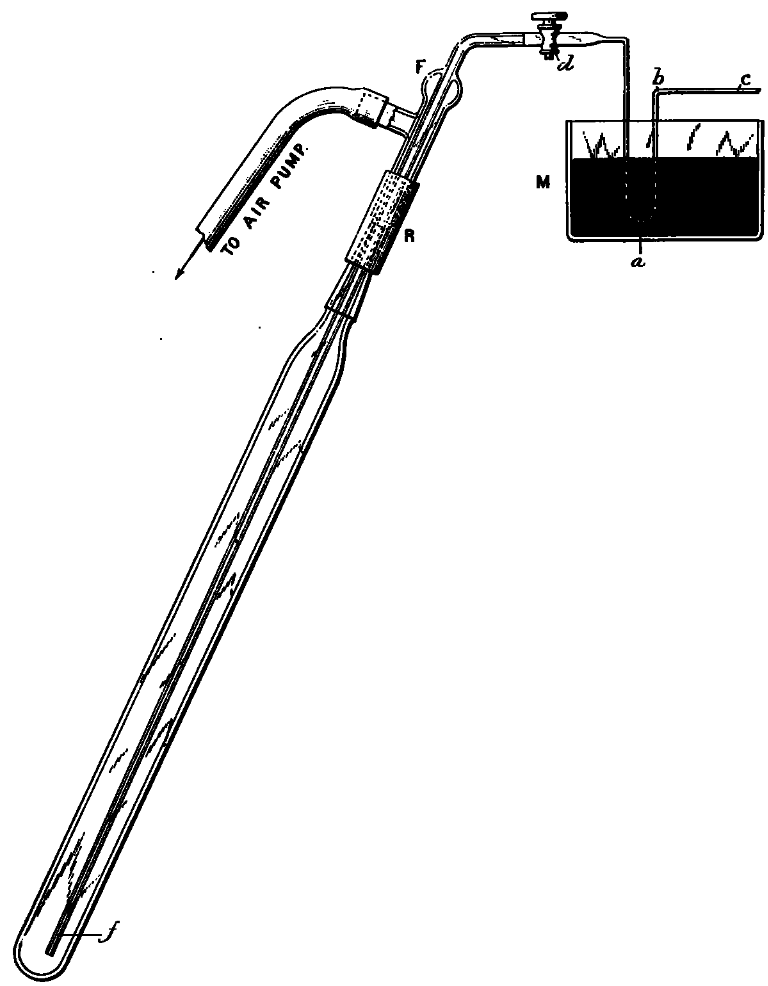


FIG. 7.—The air-pump method of filling barometer tubes.

nately exhausted pretty completely and dry air admitted while the walls are more or less continuously heated by playing over the tube with the flame from a Bunsen burner. These operations must be repeated ten or more times and the tube kept hot. Thruout these operations the mercury is excluded and the funnel tube partakes at least partly in the drying influences.

While the tube is kept quite warm and the vacuum maintained at a high point the capillary is broken at *a* and the mercury in M, which has been heated in the meantime, is permitted to flow. M need not be large enough to contain all the mercury required, but additions may be frequently made and the whole kept quite warm. The filling will take place slowly, depending upon the size of the bore of the inlet tube. The vacuum must be maintained at a high point until the mercury fills the barometer tube when the flow may be stopt by admitting air to the pump. The vessel M must also be removed if there is any tendency for the mercury to flow one way or the other by gravitation.

For the very finest effects the barometer tube can be exhausted by a Sprengel or other high vacua pump, but in this case the rubber tube connections must be replaced by glass and fused joints.

It may be remarked here, that the very high vacua with which we are familiar now-a-days in X-ray and other such tubes, are by no means essential except in the highest grade of *normal* barometers where results depend upon the absolute height of the mercurial column. In the case of instruments in which a correction is found by comparison with a normal, and especially in barographs where the results depend entirely upon differences in the position of the mercurial column, simple methods of filling give entirely satisfactory results. In these cases the pressure due to gases that may be in the vacuum is so nearly constant that no serious error is involved.

Suppose, for example, that the residual air in a barograph tube exerts a pressure of 0.1 inch, which would be inexcusably bad filling. Now, since we set the pen of the barograph to agree, from time to time, with a standard barometer, the only effect the air can have is such as results from changes in temperature or changes in the volume of the vacuum chamber. A 20° change of temperature between settings of the pen is not usual, but in this case would introduce an error of only about 0.003 inch, whence, with reasonably good filling and fairly uniform temperatures the errors from imperfect vacuum are entirely insignificant.

## THE WEATHER OF THE MONTH.

By Mr. P. C. DAY, Acting Chief, Climatological Division.

### PRESSURE AND WINDS.

The distribution of mean atmospheric pressure for September, 1908, over the United States and Canada, is graphically shown on Chart VI, and the average values and departures from the normal are shown for each station in Tables I and III.

The average sea-level pressure was highest over the upper Ohio Valley and the Middle Atlantic States where the monthly means ranged from 30.10 to 30.15 inches. A similar area with somewhat lower pressure covered the North Pacific coast. A ridge of slightly less average pressure extending eastward and westward across the central portions of the United States connected the above high areas and the pressure diminished northward and southward by moderate gradients.

Pressure averages were slightly below normal over the Canadian Northwest Provinces and at a few points in the extreme Eastern Maritime Provinces; elsewhere over all districts in the United States and Canada the normal was exceeded. Over the Middle Atlantic States it was about .05 inch above, and slightly in excess of that amount over portions of the southern Plains region, and from .05 to .10 inch above over the greater part of the Plateau and Pacific coast districts.

From August to September, 1908, there was a decided increase in pressure over nearly all districts in the United States and over the Canadian Provinces from the Lake region eastward. Over the Florida Peninsula and along the immediate Gulf coast there was a decrease ranging from .01 inch at Jacksonville, Fla., and New Orleans, La., to .08 inch at Key West, Fla. Over the upper Missouri Valley and extending northward into the Canadian Northwest Territories the pressure for September was slightly less than that for August.

Due to the ridge of high pressure extending across the central portions of the United States southerly winds were dominant over nearly all northern districts from the Atlantic to the Pacific, while over the southern portions, especially east of the Mississippi Valley, they were largely from northerly points.

Over the east Gulf and Atlantic coast States there was a general excess of wind movement, but over nearly all the remaining districts of the United States the average wind velocities were considerably less than the normal rate, the deficiency being most pronounced over the southern portion of the Plains region where the wind movement at points was from 20 to 40 per cent less than the average. The great interior districts were remarkably free from severe atmospheric disturbances, the few storm tracks being confined mostly to the more northern districts or off the Atlantic coast.

### TEMPERATURE.

September, 1908, was unusually warm over the greater part of the United States and over the whole of Canada as far north as the field of observations extends.

From New England westward over the Lake region, the Ohio, Mississippi, and Missouri valleys to the Rocky Mountains the average for the month ranged from 3° to 7° above the normal.

Over the Atlantic coast districts from southern New England to Florida, along the Gulf coast, in portions of Texas, and at points on the Pacific coast, the average temperature was below the normal by small amounts.

During the first three weeks the temperatures were above the normal over nearly all districts, except along the Atlantic coast, being especially high during the second and third weeks over the great interior agricultural districts. Cooler weather prevailed during the latter part of the month over the districts from the Great Plains westward, but unseasonably warm weather continued to near the end of the month over the districts from the Mississippi Valley eastward. The mean temperature during the second, third, and fourth weeks over the Lake region, Ohio and upper Mississippi valleys, ranged from 10° to 15° per day above the average. During the third week cool weather set in over the Pacific coast and extending eastward covered the Rocky Mountain districts during the following week and the remaining districts farther east by the end of the month.

Maximum temperatures from 90° to slightly above 100° were recorded at intervals during the month over all districts east of the Rocky Mountains, except from the Appalachian Mountains eastward to the Atlantic, over the lower Lake region and New England. Maximum temperatures above 100° were recorded in the interior valleys of California and southwestern Arizona, and they were above 90° over most of the Plateau region.

Minimum temperatures near the freezing point occurred during the latter part of the month as far south as central Texas and from thence northeasterly over the central Mississippi Valley district to the lower Lake region and portions of New England. Temperatures below 20° were recorded over large portions of the central Rocky Mountain and Plateau districts, and below 10° at exposed points in the mountains of Colorado and Wyoming. The minimum temperatures during the latter part of the month were among the lowest ever recorded for September at many points from the north Pacific coast southeasterly over the Plateau, Rocky Mountain, and Great Plains districts to central Texas.

### PRECIPITATION.

Precipitation was unusually heavy along the Gulf coast, southeastern Georgia, and over most of the Florida Peninsula, where some very heavy monthly falls occurred, the amount recorded at Jacksonville, 21.79 inches, being the greatest monthly fall in the history of that station. Amounts from 2 to 6 inches occurred over the districts east of the Appalachian Mountains from Maryland southward, and similar amounts were received from Missouri and eastern Kansas southward over most of Arkansas, Oklahoma, Louisiana, and eastern Texas. Unusually heavy precipitation for the section occurred over the central portions of Utah, where the amounts were several times greater than the average.

The severe drought inaugurated during the latter part of August over the Lake region, Ohio and upper Mississippi valleys and adjoining districts continued into September with increasing severity. No general rains occurred over large portions of the above districts from about the 17th of August